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Two- Echelon Inventory System With Advertisement Policies Under Quadratic Price Dependent Demand

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Abstract

Basically, the world is one huge supply chain. Supply Chain Management(SCM) is an essential element to operational efficiency. SCM can be performed to customer satisfaction and company success, as well as within societal settings and it can help to improve quality of life.In this context, two-echelon supply chain model is developed considering a single manufacturer and single retailer. The main objective of this paper is to demonstrate the optimality of the decision variables and objective function for respective establishments as well as for the entire chain with two kinds of advertisement policies under quadratic price dependent demand. The mathematical model is developed in two cases. First, the expression for the annual net revenue of the retailer and manufacturer is extended separately and then for the coordinated supply chain as a function of annual ordering/set up costs,carrying cost, transportation cost, screening cost, packaging cost and advertisement costs (for both television & online) with numerical examples.

Keywords: Two-Echelon inventory system, Quadratic price dependent demand, Advertisement policies , Annual net revenue.

1.Introduction

Supply chain management plays a large role in the world we live in. It includes retailer, distributor, producer, supplier, along with consumer. In general these consumers will be having different intent in their mind, which are contradicting among them. Every part of the supply chain has its own inducement and information state, and nobody has the ability to upgrade whole supply chain execution. In a two-echelon supply chain beneath this situation, both retailer and manufacturer need to amplify their overall revenues leading to twofold marginalization of the framework. This issue could be wiped out, just, when whole supply chain is worked in a facilitated mode. Along these lines, in supply chain that is two-echelon synchronization among retailer and manufacturer is a prominent issue to enhance the channel execution.

Due to the coordination of the supply chain, the downstream associate will receive proper contract parameters from upstream associate so that their benefit augmenting targets are adjusted to the goal of the supply chain. An appropriately outlined coordination contract totally wipes out twofold marginalization, as well as acquires win-win circumstance for every stakeholder of the supply chain.The value chain partners are the retailer and manufacturer. Consumers demand is identified and then satisfied through a supply chain and also attempts are made to increase demand through advertising to earn a profit.

A quote has been said by Henry Ford, "The man who stops advertising to save money, is like the man who stops the clock to save time". Since advertising plays a very important role in today's age of competition and which has become a necessity for everybody in today's day to day life. Advertising is the best way to communicate to the customers and it helps to inform the customer about the brand available in the market and the variety of products useful to them. Yet there lots of ways to advertise , but in this two-echelon supply chain system we considered only two modes of advertising policies that, one is an online advertising for manufacturer , since generally manufacturer wants to market his brand nationally, or worldwide, for that internet is the very effective way to produce the advertisement. It is not only for that the internet also allows the people to connect with one another all over the world and creates a valuable customer group. Secondly, television advertising policy is for the retailer, since retailer wants to make his profit by creating a large number of customers group from his surroundings or locally.TV is the king of media and is the easy going, non-invasive, yet targeted advertising medium. In the customers mind TV advertisement creates awareness of products, service, and company and most importantly the brand.

This paper elucidates about two-echelon inventory system withtwo advertisement policies under quadratic price dependent demand with the inclusion of screening cost, packaging cost and advertisement costs (for both television & online),then presents a numerical example to conclude the proposed work. Further, the structure of this work is in brief as follows, Section 2 presents the literature review of the previous workscited. Section 3 presents notations and assumptionswith the discussion of two model problems, Section 4gives numerical example and in section 5concludesthe proposed work.

2.Literature Review

In most recent three decades, broad examination has been performed in the zone of coordination of supply chain. Scientists have investigated different parts of organizing supply chain under a varied set of presumptions. Under established price-conscious demand these issues are analyzed. In the literature different systems were proposed, that includes buy back option, discount on quantity, credit facility, flexible quantity contract. Banerjee[1] has introduced an innovative and effective concept of Joint Economic Lot Size (JELS). The basic assumptions of Banerjee are that continuous production will be carried out by the manufacturer as per the single retailer order. In general, these retailers experience the deterministic demand. The value chain partners are the retailer and manufacturer. Manufacturer is equipped with complete information of the product demand from end customer and they will have great association with retailers which in turn will help manufacturer to get the knowledge about the customer. Many more writers like Hall [2]and Li et al. [3], have also demonstrated that the combined thoughtfulness of economic lot size substantially minimizes the total combined cost per annum.

Quantity discount contract is considered as the most effective and popular among the available mechanisms due its ease (Cachon, [4]). By taking multiple buyers into consideration they have taken the earlier studies forward. In addition, most of the studies have considered demand that is price-sensitive, for case in point, Weng [6], Weng [5]. We referred to Sarmah et al. [7]for a broad study of the research on quantity discount. Enormous amount of attention was paid towards inventory system several decades in the past. On the other hand, good number of scholars described the best possible inventory system from one company's point of view and totally ignored the optimization of the cost or profit of the complete supply chain. Supply chain synchronization has turned into an imperative segment for upgrading the productivity and responsiveness of the chain. At the point where there is no coordination, the supply chain parts act autonomously to augment their own particular benefit, which does not guarantee that the parties all in all achieve an ideal result (Sajadieh and Jokar,[8]) both from financial and ecological perspectives. At the point where there is coordination, the aggregate store network benefit/expense is expanded/minimized. However, the benefits out of coordination will go to the merchant as the purchaser is the person who will be operation off its ideal approach. Notwithstanding, the losing party is generally repaid in facilitated supply chain (Jaber and Zolfaghari, [9]). This work explores the inventory strategy for a merchant-purchaser supply chain when the players have private (benefit) and societal (natural) goals to accomplish. The merchant-purchaser coordination issue has been accepting an expanding consideration by specialists and academicians (Jaber and Zolfaghari [9] and Toptal et al. [10]). In this work, the stream of study is addressing the purchaser-merchant coordination issue is alluded to as a joint economic lot sizing (JELS) issue, with the latest survey in Glock [2].

An EOQ model that was proposed by Wahab et al. [12] for the composed supply chain in two-level, considering blemished things and ecological effect, that is consolidated into the ideal strategy of the supply chain considering carbon discharge costs. Also, a two-level supply chain scientific model incorporating emanation expenses identified with producer's methods. According to the European Union Emissions Trading System (EU-ETS) tax and emission penalty was taken into account by them, and crated good number of numerical illustrations in order to demonstrate the most advantageous resolution approach over varied likely situations. A mathematical model was introduced by Darwish and Goyal [14]by considering the single-buyer single-vendor problem under vendor managed inventory configuration. The other related recent articles addressing supply chain coordination mechanism underprice driven demand include, Kim et al. [15] and Parthasarathi et al. [16]. Nagaraju et al. [17] developed a two-echelon inventory system with the price sensitive demand considering the effect of wholesale price index (WPI) and consumer price index (CPI). Syamsundar et al.[18] introduced a two level supply chain system under linear price driven demand for the optimality of replenishment quantity, inventory ratio and gross profit of the supply chain.Burra. K.K ,Nagaraju, D.(2014)[19] developed an Optimality of inventory decisions and shipment policies in a two-echelon inventory system under quadratic price dependent demand.

Khouja and Robbins (2003) [22] investigated the optimal expense of the local advertising and the ordering quantity under the newsboy framework. However, most of the above literature on co-op advertising considered the co-op advertising policies. Huang, Li (2002), Zhu, and Chau (2002) developed independently a cooperative advertising model for a one-manufacturer–one-retailer supply chain. Huang and Li (2001) [21] further discussed the cooperative advertising issue for the supply chain with one manufacturer and one retailer. Xie and Ai (2006) [27] extended the models developed by Huang and Li (2001) [21] and Li et al. (2002) [23] to the case, where the manufacturer's marginal profit is relatively small. Yue, Austin, Wang, and Huang (2006), Huang and Li (2001) [21] in developing a price discount model to coordinate the advertising expenses of the two parties. Later an optimal cooperative advertising integration strategy for organizations having a direct online channel was developed. Sheng.et.al (2011) [24] developed the cooperative advertising model that involves one-manufacturer and two-retailers.

This work is mainly focused on the development of a two-echelon inventory system with advertisement policies for a non-coordinated supply chain and a coordinated supply chain under quadratic price dependent demand. Further, numerical illustration is carried out to compare the coordinated and non-coordinated supply chain system for the optimality of decision parameters and objective function.

3.Mathematical Model Formulation

To establish the mathematical model,the following assumptions and notations are used.

Assumptions

- This supply chain consists of a single retailer, a single manufacturer for a single product
- Demand is expressed as a quadratic function of retailer's unit selling price

- Replenishment batch size at the manufacturer is an integer multiple of replenishment quantity at the retailer
- No shortages are allowed
- The initialization cost for an advertisement is the amount spent separately by the retailer and the manufacturer to get connected with television and online ad agencies
- Inspecting and packaging can be made as a disparate process by a retailer & manufacturer

Notations

D = Annual demand rate of the retailer(units/yr) = $\alpha - \beta P_R - \gamma {P_R}^2$,

where $\gamma > 0, \beta > \gamma, \alpha \gg \beta$

λ = Number of shipments from the manufacturer to retailer for the cycle time, T (integer,decision variable)

k = Interest rate, (in INR/INR/yr)

Retailer Side

P_R = Unit selling price at the retailer, INR/unit

S_R = Retailer's ordering cost per order for the cycle time,T INR/order

C_R = Retailer's unit cost,INR/unit

τ_R = Fixed transportation cost , INR/shipment

X_R = Retailer's Screening cost,INR/unit

E_R = Initialization cost for packaging equipment,INR

m = Cost of material used for packaging, INR/parcel

p =Number of parcels

I_R = Initialization cost for television advertisement

n = Number of times the advertisement is telecast

t = Cost of telecasting the advertisement once

Q_R = Shipment quantity in each shipment from the manufacturer to replenish the inventory at retailer for the cycle time , T (decision variable) ($Q_R = DT$) (in units)

Manufacturer Side

S_m = Manufacturer's setup cost per setup for the cycle time, λTINR/setup

C_m = Manufacturer's unit cost,INR/unit

τ_m = Fixed transportation cost,INR/shipment

I_m = Initialization cost for online advertisement

C = (CPM) cost per thousand impressions

M = Number of impressions

X_m = Manufacturer's Screening cost, INR/unit

E_m = Initialization cost for packaging Equipment

m_1 = Cost of material used for packaging, INR/parcel

p_1 = Number of parcels

Q_m = Replenishment batch size at the manufacturer to replenish the inventory at the retailer for the cycle time, $\lambda T(Q_m = \lambda Q_R = D(\lambda T))$ (in units)

$\psi_R(Q_R)$ Annual net revenue of the retailer expressed in terms of Q_R

$\psi_M(\lambda, Q_R)$ Annual net revenue of the manufacturer expressed in terms of λ, Q_R

$\psi_S(\lambda, Q_R)$ Annual net revenue of the supply chain expressed in terms of λ, Q_R

3.1 Non – Coordinated Supply chain

For non-coordinated supply chain, the retailer choose his own optimal ordering quantity Q_R and manufacturer chooses his own optimal number of shipments, λ with respect to the retailer's optimal ordering quantity.

Retailer Optimal Policy:

The retailer's annual net revenue consists of the following elements,

- Ordering cost : $\frac{(\alpha-\beta P_R-\gamma {P_R}^2)}{Q_R} S_R$
- Carrying cost :$\frac{Q_R}{2} C_R k$
- Screening cost : $\frac{(\alpha-\beta P_R-\gamma {P_R}^2)}{Q_R} X_R$
- Packaging cost : $E_R + mp$

- Transportation cost : $\frac{(\alpha-\beta P_R-\gamma {P_R}^2)}{Q_R}\tau_R$
- Television Advertising cost : $I_R + nt$

The retailer's annual net revenue is obtained by subtracting the annual ordering cost, carrying cost, screening cost, packaging cost, transportation cost and television advertisement cost from the gross revenue.

$$\psi_R(Q_R) = (P_R - C_R)(\alpha - \beta P_R - \gamma {P_R}^2) - \frac{(\alpha-\beta P_R-\gamma {P_R}^2)}{Q_R}S_R - \frac{Q_R}{2}C_R k - \frac{(\alpha-\beta P_R-\gamma {P_R}^2)}{Q_R}X_R - (E_R + mp) - \frac{(\alpha-\beta P_R-\gamma {P_R}^2)}{Q_R}\tau_R - (I_R + nt) \quad (1)$$

The Annual net revenue of the retailer is concave in terms of Q_R.The optimal replenishment quantity ${Q_R}^*$ is obtained as follows,

Taking the first order partial derivative of Eq (1) with respect to Q_R,we have $\frac{\partial}{\partial Q_R}(\psi_R(Q_R)) = 0$.

$$\frac{(\alpha-\beta P_R-\gamma {P_R}^2)}{Q_R}(S_R + \tau_R + X_R) = \frac{C_R k}{2} \text{and} {Q_R}^* = \sqrt{\frac{2(\alpha-\beta P_R-\gamma {P_R}^2)(S_R+\tau_R+X_R)}{C_R k}} \quad (2)$$

Now taking the second order partial derivative of Eq. (1), we have

$$\frac{\partial^2}{\partial {Q_R}^2}(\psi_R(Q_R)) = -\frac{2(\alpha-\beta P_R-\gamma {P_R}^2)(S_R+\tau_R+X_R)}{{Q_R}^3}$$

(3)

From Eq (3), the principal minor of Hessian matrix, $H(Q_R) = \frac{\partial^2}{\partial {Q_R}^2}(\psi_R(Q_R)) < 0$ for all values of Q_R. Hence Q_R becomes optimum and $\psi_R(Q_R)$ is strictly said to be concave.

Manufacturer Optimal Policy:

The manufacturer's annual net revenue consists of the following elements,

- Ordering cost : $\frac{(\alpha-\beta P_R-\gamma {P_R}^2)}{Q_R\ \lambda}S_M$
- Carrying cost : $\frac{(\lambda-1)Q_R}{2}C_M k$
- Screening cost : $\frac{(\alpha-\beta P_R-\gamma {P_R}^2)}{Q_R}X_M$
- Packaging cost : $E_M + m_1 p_1$
- Transportation cost : $\frac{(\alpha-\beta P_R-\gamma {P_R}^2)}{Q_R}\tau_M$
- Online Advertising cost : $I_M + \frac{CM}{1000}$

The manufacturer's annual net revenueis obtained by subtracting the annual ordering cost, carrying cost, screening cost, packaging cost, transportation cost and online advertisement cost from the gross revenue.

$$\psi_M(\lambda, Q_R) = (C_R - C_M)(\alpha - \beta P_R - \gamma {P_R}^2) - \frac{(\alpha - \beta P_R - \gamma {P_R}^2)}{Q_R\ \lambda} S_M - \frac{(\lambda - 1)Q_R}{2} C_M k - \frac{(\alpha - \beta P_R - \gamma {P_R}^2)}{Q_R} X_M - (E_M + m_1 p_1) - \frac{(\alpha - \beta P_R - \gamma {P_R}^2)}{Q_R} \tau_M - \left(I_M + \frac{CM}{1000}\right) \quad (4)$$

Proposition:1

For given value of Q_R, the optimal value of λ, λ^* always satisfies the following conditions:

$$\lambda^*(\lambda^* - 1) \le \frac{2(\alpha - \beta P_R - \gamma {P_R}^2)}{{Q_R}^2 C_M k} S_M \le \lambda^*(\lambda^* + 1)$$

(5)

Proof:

For given value of Q_R, the optimal value of λ, λ^* always satisfies the following conditions ,

$\psi_M(\lambda^*) \ge \psi_M(\lambda^* - 1)$--- (i)and

$\psi_M(\lambda^*) \ge \psi_M(\lambda^* + 1)$ --- (ii)

Substituting the relevant values in eq.(4) for the condition (i), and with further simplifications, we have$\frac{2(\alpha - \beta P_R - \gamma {P_R}^2)}{{Q_R}^2 C_M k} S_M \ge \lambda^*(\lambda^* - 1)$(6)

Similarly,substituting the relevant values in eq.(4) for the condition(ii),and with further simplifications, we have $\frac{2(\alpha - \beta P_R - \gamma {P_R}^2)}{{Q_R}^2 C_M k} S_M \le \lambda^*(\lambda^* + 1)$

(7)

Hence the following expression can be obtained from Eqs. (6) &(7) ,

$$\lambda^*(\lambda^* - 1) \le \frac{2(\alpha - \beta P_R - \gamma {P_R}^2)}{{Q_R}^2 C_M k} S_M \le \lambda^*(\lambda^* + 1)$$

Then, Obviously we can derive the annual net revenue of the supply chain is equal to the sum of retailer's, and manufacturer's annual net revenues,

$$\psi_S(\lambda, Q_R) = \psi_R(Q_R) + \psi_M(\lambda, Q_R)$$

(8)

3.2. Coordinated Supply chain

For coordinated supply chain, the optimal integrated policy can be derived as the joint annual net revenue of both retailer and manufacturer $\psi_S(\lambda, Q_R)$ with quadratic price dependent demandby,

$$\psi_S(\lambda, Q_R) = (P_R - C_M)(\alpha - \beta P_R - \gamma {P_R}^2) - \frac{(\alpha-\beta P_R-\gamma {P_R}^2)}{Q_R}\left(S_R + \frac{S_M}{\lambda} + \tau_R + \tau_M + X_R + X_M\right) - \frac{Q_R k}{2}(C_R + (\lambda-1)C_M) - (E_R + E_M + mp + m_1p_1) - \left(I_R + I_M + nt + \frac{CM}{1000}\right) \qquad (9)$$

For a given value of λ, the annual net revenue of the supply chain is concave in terms of Q_R.The optimal ordering quantity ${Q_R}^*$ is obtained as follows,

Taking the first order partial derivative of Eq. (9) with respect to Q_R,we have

$$\frac{\partial}{\partial Q_R}\left(\psi_S(\lambda, Q_R)\right) = 0 \Rightarrow {Q_R}^* = \sqrt{\frac{2(\alpha-\beta P_R-\gamma {P_R}^2)\left(S_R+\frac{S_M}{\lambda}+\tau_R+\tau_M+X_R+X_M\right)}{(C_R+(\lambda-1)C_M)k}} \qquad (10)$$

Now taking the second order partial derivative of Eq. (9), we have

$$\frac{\partial^2}{\partial {Q_R}^2}\left(\psi_S(\lambda, Q_R)\right) = -\frac{2(\alpha-\beta P_R-\gamma {P_R}^2)\left(S_R+\frac{S_M}{\lambda}+\tau_R+\tau_M+X_R+X_M\right)}{{Q_R}^3} \qquad (11)$$

From Eq.(11), the principal minor of Hessian matrix, $H(Q_R) = \frac{\partial^2}{\partial {Q_R}^2}\left(\psi_S(\lambda, Q_R)\right) < 0$ for all values of λ, Q_R. Hence λ and Q_R becomes optimum.Then $\psi_S(\lambda, Q_R)$ is strictly said to be concave.

Proposition:2

For given value of Q_R, the optimal value of λ, λ^* always satisfies the following conditions:

$$\lambda^*(\lambda^*-1) \leq \frac{2(\alpha-\beta P_R-\gamma {P_R}^2)}{{Q_R}^2 C_M k} S_M \leq \lambda^*(\lambda^*+1) \quad (12)$$

Proof:

For given value of Q_R, the optimal value of λ, λ^* always satisfies the following conditions ,

$\psi_S(\lambda^*) \geq \psi_S(\lambda^*-1)$ --- (iii) and

$\psi_S(\lambda^*) \geq \psi_S(\lambda^*+1)$ --- (iv)

Substituting the relevant values in eq.(9) for the condition (iii), and with further simplifications, we have $\frac{2(\alpha-\beta P_R-\gamma P_R{}^2)}{Q_R{}^2 C_M k} S_M \geq \lambda^*(\lambda^*-1)(13)$

Similarly, substituting the relevant values in eq.(9) for the condition (iv),and with further simplifications, we have $\frac{2(\alpha-\beta P_R-\gamma P_R{}^2)}{Q_R{}^2 C_M k} S_M \leq \lambda^*(\lambda^*+1)$ (14)

Hence the following expression can be obtained from Eqs. (13) &(14) ,

$$\lambda^*(\lambda^*-1) \leq \frac{2(\alpha-\beta P_R-\gamma P_R{}^2)}{Q_R{}^2 C_M k} S_M \leq \lambda^*(\lambda^*+1)$$

4.Numerical example

A numerical example is discussed and tabulated here to illustrate the proposed model. Consider an inventory system with the following parametric values,

$S_R = 100,\ S_M = 300,\ P_R = 160,\ C_R = 140,\ C_M = 100,\ \tau_M = 400,\ \tau_R = 100,\ k = 18\%,\ X_R = 0.5,\ X_M = 0.6,\ E_R = 3000,\ E_M = 5000,\ I_R = 10{,}000,\ I_M = 20{,}000,\ m_1 = 5,\ p_1 = 1000,\ m = 3,\ p = 1000,\ t = 200,\ n = 100,\ C = 20,\ M = 400{,}000,\ \alpha = 10{,}000,\ \beta = 5,\ \gamma = 0.2$.

Table 1: Optimal values of Decision variables and objective function

Description	D(units)	$Q_R{}^*$(units)	λ^* (an integer)	$Q_M{}^*$ (units)	$\psi_R{}^*$(INR)	$\psi_M{}^*$(INR)	$\boldsymbol{\psi_S}{}^*$(INR)
Without coordination	4080	254.8	2.00	509.6	39,178.99	114,090.29	**153,269.28**
With coordination	4080	540.17	1.00	540.17	37,279.44	119,908.25	**157,187.69**

5.Conclusion

In this paper, a two-echelon supply chain inventory system consisting of a single manufacturer supplying a single kind of product to a single retailer is considered. A mathematical model for a two-echelon inventory system with two kinds of advertisement policies is developed, under quadratic price dependent demand for a coordinated and non-coordinated supply chain.A numerical example is provided to demonstrate its practical usage.

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